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DEVELOPMENT OF A TOOL FOR ESTIMATION OF TOTAL COST OF COMMUTE IN AUSTIN

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DEVELOPMENT OF A TOOL FOR ESTIMATION OF TOTAL COST OF COMMUTE IN AUSTIN

by

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ABSTRACT

DEVELOPMENT OF A TOOL FOR ESTIMATION OF TOTAL COST OF COMMUTE IN AUSTIN

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While intelligent consumers aim to investigate all costs and benefits prior to making travel mode decisions, much of the information needed is not readily available to them. There is even less knowledge of the costs and benefits to society that reflect those decisions. If there were a tool for transportation users to see the actual cost of their commute they would be able to make more informed decisions about travel. The purpose of this research is to create the background information for a tool in the form of a web application that will enable users to visualize the individual and societal costs and benefits of their own commutes. The information will materialize in the form of eight equations for estimating internal and external cost by four different modes of travel.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

When considering transportation costs per trip, most automobile owners will probably cite only the costs of gasoline. Other user costs that are often overlooked but make up a large part of vehicle operation and ownership include oil, maintenance, the initial purchase, license, and insurance. People who use public transit will most likely consider the cost of their fare as the only component of the total trip cost.

A major component of transportation costs that is often overlooked is made up of non-market costs, such as value of time and risk of accident. These costs vary widely across users due to their subjectivity and are often quite complicated to quantify.

Effective transportation planning requires an understanding of more than just user costs. Transportation systems impose external costs on society, such as congestion and air pollution. External costs are indirect and largely non-market, making them difficult to measure. However, they should not be ignored because they are real and significant costs that often increase with the use of motorized vehicles.

The goal of this research is to increase users' knowledge of the cost of their mode choice and the resulting impact it has on society. This might result in some users adjusting the mode of their commute. It would be particularly successful if this resulted in increasing public transit ridership.

The final product will be a web application where a user can input the origin and destination of their own commute on a map and choose a bus route to compare it with. Provided the user is knowledgeable of the bus system, they will choose a route that coincides with their trip. Lastly, they will choose a time at which they will be traveling.

This information will then be input into eight equations to compute cost. The modes for which cost will be calculated are auto, transit bus, bike, and walk. For each mode the internal (personal) and external (societal) costs will be calculated.

2 BACKGROUND

The inspiration for this project came from a similar application produced by Discourse Media for Metropolitan Vancouver. Other sources used to develop the equations for this model used include papers that have researched the internal and external costs of transportation. Based upon the review of previous work, judgments regarding what costs should be included have been made. All cost estimate values have been converted to 2015 United States Dollars and further adapted to an Austin, Texas context.

2.1 COST OF COMMUTE CALCULATOR, DISCOURSE MEDIA AND GEORGE POULOS

This application allows one to compare the costs of travelling by different forms of transportation in Metro Vancouver in a way that takes the broad impacts into account. These include both personal costs borne directly by the individual and costs borne by society at large.

The starting point for a user of the Vancouver application is choosing a bus route and distance to compare mode costs. While this makes sense for people who are familiar with the bus system, it is confusing for people who commute by car every day. For the preliminary version of the Austin application, the user will provide a bus route and direction. This resolves the problem of most routes having different speeds in different travel directions at different times of day. However, it still relies on the user having experience with the bus routes. For future development of the Austin application, it is recommended to include Google Maps of Capital Metro's Trip Planner reference to match bus routes to users' commutes.

It should also be noted that the Vancouver analysis pertains only to peak hour utilitarian trips on weekdays. The application for Austin will include four times of day: AM Peak

(6:00 – 8:59), Midday (9:00 – 15:59), PM Peak (16:00 – 18:59) and Nighttime (19:00 – 5:59).

The breakdown costs show cost to user and society for four different modes of travel: bus, automobile, bike, and foot. It also outputs a bar graph to visually depict this information, as well as cost breakdown graphs for each mode.

2.2 AN ANALYSIS OF THE FULL COSTS AND IMPACTS OF TRANSPORTATION IN SANTIAGO DE CHILE, CHRISTOPHER ZEGRAS AND TODD LITMAN

This study summarizes research on full transportation costs to help in policy making and planning in Santiago (Ref). It goes through fixed and variable costs of ownership, as well as costs of time, accidents, congestion, facilities, land value, pollution, noise pollution, resource consumption, land use, and others. As it accounts for both internal and external costs of transportation, it serves as a valid source for cost estimation. However, the paper is considerably dated, as it was published in 1997, and reliability should be checked.

2.3 UPDATE OF THE HANDBOOK ON EXTERNAL COSTS OF TRANSPORT, RICARDO-AEA

Ricardo-AEA, or Ricardo Energy & Environment, is a global sustainability consultancy. After a mandate on charging heavy-duty vehicles for the use of certain infrastructure in the EU was amended in 2006, The European Commission commissioned the IMPACT study in order to summarize the existing scientific and practitioner's knowledge. The Handbook on external costs estimation was produced in 2008. Ricardo-AEA took on the task of updating the Handbook with new developments in research and policy. The sections used in this application include the external costs of congestion, noise, air pollution, climate change, and infrastructure wear and tear. Because the updated Handbook was published in 2014, it serves as a more relevant source than the paper by

Zegras and Litman. However, all costs are estimated in Euro fractions and have been converted to US Dollars for comparison.

2.4 BICYCLING AND WALKING IN THE UNITED STATES 2014 BENCHMARKING REPORT, THE ALLIANCE FOR BIKING AND WALKING

The Alliance for Biking & Walking is the North American coalition of state and local bicycling and walking advocacy organizations. The Alliance's Benchmarking Project aligns with and helps track the goals and objectives of national public health initiatives by promoting cross-sector collaboration, data-driven decision-making, and broader access to bicycling and walking opportunities. While the total cost studies provide useful information about the auto and bus modes, they are lacking in pedestrian and cyclist analyses. The Benchmarking Project serves as a reliable and relevant source for bicycling and walking data in Austin and provides data comparing Austin to the other 52 most populous cities in the United States. These data include commuter mode shares, miles of existing and planned biking and walking infrastructure, and fatality rates.

3 MODAL CHARACTERISTICS AND COST STRUCTURE

The National Household Travel Survey (NHTS) is periodically conducted by the U.S. Department of Transportation's Federal Highway Administration (FHWA) to assess the mobility of the American public. The following data was extracted from the 2009 National Household Travel Survey for the 11 county Austin District. The Travel Day Trip File contains information about mode choice by trip (as reported by respondent).

Table 1: Mode Choice in the Austin District, 2009

Mode	Number of Trips	Percent
Auto	11,825	89.7%
Bus	79	0.6%
Walk	1,159	8.8%
Bike	115	0.9%

Source: NHTS 2009

The Alliance for Biking and Walking reports mode share values for walking and biking as 2.6% and 1.3%, respectively (2014), these numbers appear to be closer to the observed shares in Austin.

3.1 DOLLAR VALUE OF TIME

One of the biggest factors considered when choosing mode of travel is time. In order to accurately estimate the cost of each mode, the dollar value of time for the Austin population has to be calculated.

There are several widely used methods for determining the dollar value of time. The two used in this report divide the median per capita income by a time value. Two different time values were used. The first conservative method is to divide median personal income by the total number of hours in the year (8,760). The second, a less conservative method, is to divide median personal income by the number of working hours in a year (2,080).

Transit riders in Austin primarily live in three counties: Travis, Williamson and Hays Counties. The United States Census Bureau provides the 2013 per capita income for each of these counties. A weighted average of these three incomes was calculated based on their 2013 populations, as shown in Table 2.

Table 2: Average per Capita Income for Region

County	Per Capita Income in past 12 months (2013 dollars)	Population, 2014 Estimate	% of Total Population	Weighted Average Income
Travis	$33,206	1,122,748	63.42%	$21,057.83
Williamson	$31,070	471,225	26.62%	$8,269.60
Hays	$26,873	176,483	9.97%	$2,678.76
Sum		1,770,456		$32,006.19

Source: US Census 2013

The dollar per hour value when dividing per capita income by the total number of hours in a year is:

Equation 1: Value of Time, total hours

$$\frac{\$}{hr} = \frac{\$32{,}006}{8760hrs} = \$3.65/hr$$

The dollar per hour value when dividing per capita income by the total number of working hours in a year is:

Equation 2: Value of Time, working hours

$$\frac{\$}{hr} = \frac{\$32{,}006}{2080hrs} = \$15.39/hr$$

Incorporating an inflation rate of 2.1%, this second value is $15.72 in 2015 USD. A third value of time is also used in practice. The Texas Transportation Institute (TTI) recommends a value of time of $17.67 per hour in their 2015 Urban Mobility Report (Schrank). The in-vehicle value of travel time used in the equations for the Austin application, VOT_{IV}, is $15.72.

3.11 IN-VEHICLE VS. OUT-OF-VEHICLE VALUE OF TIME

It has been shown that a travelers' perception of time varies depending on whether they are moving or still (waiting) (Iseki). For this reason, two values of time are used to compute the cost of traveling by bus. If the time to walk to and from bus stops is to be included in future developments of the Austin application, a third value of time for walking should also be considered.

In a study titled, "Weighting Waiting," authors Levinson, Harder, Bloomfied, and Winiarczyk found that ramp delay is 1.6 to 1.7 more onerous than delay on freeways using traditional computer-assisted stated-preference data (Levinson). Several studies reviewed by Wardman (2001) support the rule of thumb used in practice, where walking and waiting time are valued twice as much as in-vehicle time.

For simplification, out-of-vehicle travel time, VOT_{OV}, will be weighted as in practice, 2 times the value of in-vehicle travel time ($31.44).

3.2 PASSENGER VEHICLE

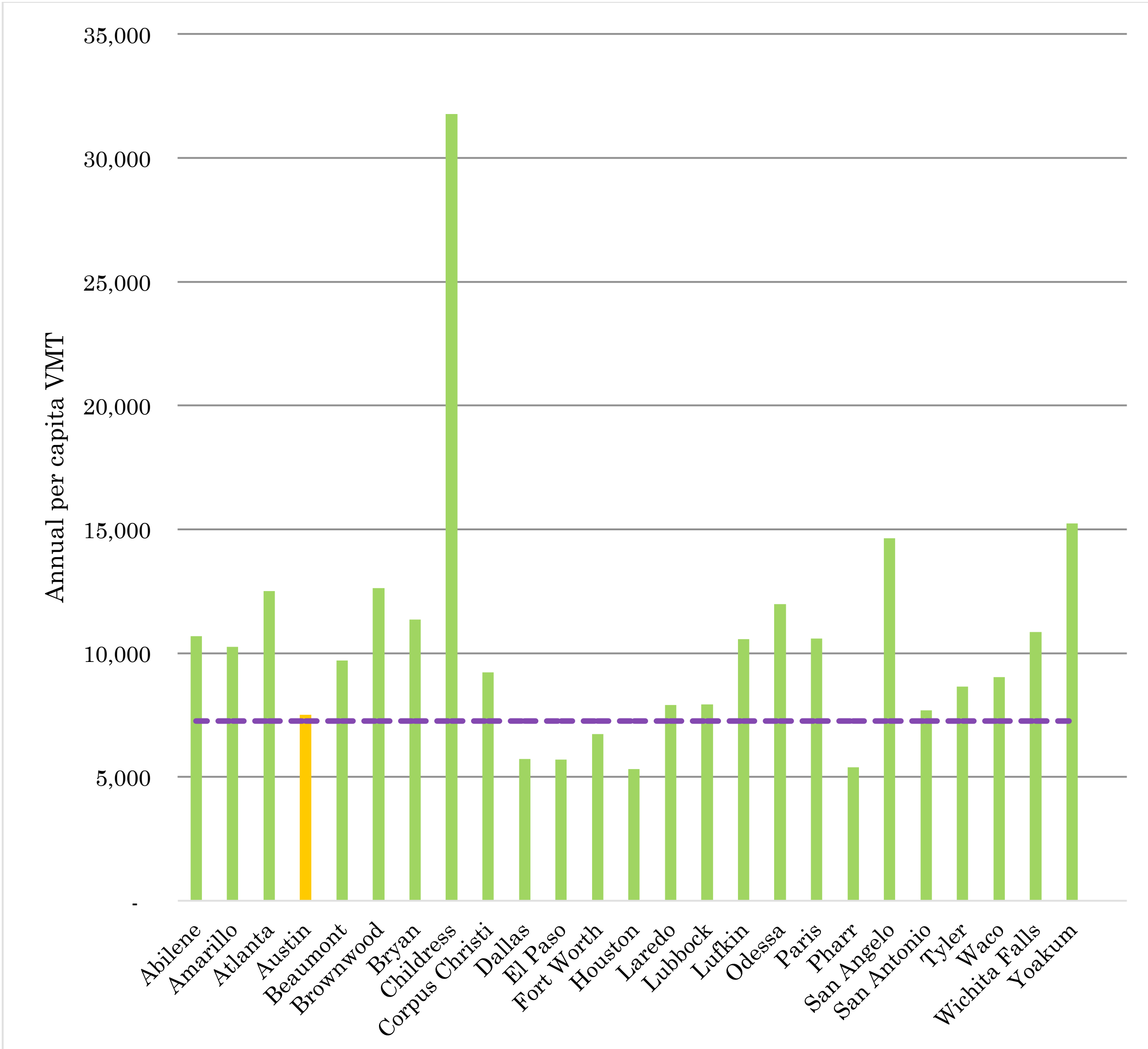
According to the NHTS, auto trips make up about 90% of all trips made in the Austin District. Although this number is fairly large, the number of annual vehicle miles traveled (VMT) per capita in the Austin District is lower than that of the entire state of Texas and the United States as a whole (Table 3).

Table 3: Annual VMT per Capita, 2014

	Daily Vehicle Miles (9/1/2013 thru 8/31/2014)	SDC Population Estimate	Annual VMT per capita
United States	8,170,547,945	317,297,938	9,399
Texas	499,867,593	25,145,561	7,256
Austin District	37,746,723	1,834,298	7,511
Travis County	18,068,121	1,024,266	6,439

Source: TxDOT DISCOS FY 2014, US Census 2014

Figure 1 shows the annual VMT per capita in the Austin District compared to other Texas Districts and the Texas average (shown in purple).



Source: TxDOT DISCOS FY 2014

Figure 1: Annual per capita VMT, FY 2014

These numbers, however, contradict the per capita VMT reported by USDOT passenger miles and US Census Bureau population data which suggest the annual VMT per capita in the United States as being around 13.5 thousand miles.

3.21 INTERNAL (PERSONAL) COST OF TRAVEL BY PASSENGER VEHICLE

The final equation for the internal cost of travel by passenger vehicle is shown below. The units for each cost equation are in US dollars. All values are per passenger mile, so they are multiplied by the shortest path distance given by the shortest path between the origin and destination inputs. The components of auto travel cost include the per mile ownership cost, given by AAA, the internal cost of auto accidents, and the value of time divided by the average driving speed for the given origin, destination, and time of day.

Equation 3: Internal Cost of Travel by Passenger Vehicle

$$U_{AUTO,INTERNAL} = D_{O,D}(C_{AUTO} + C_{AUTO,INT,ACCIDENT} + \frac{VOT_{IV}}{V_{AUTO,O,D,TOD}})$$

Where: $U_{AUTO,INTERNAL}$ = the internal cost of travel by passenger vehicle

$D_{O,D}$ = the shortest path distance between origin O and destination D

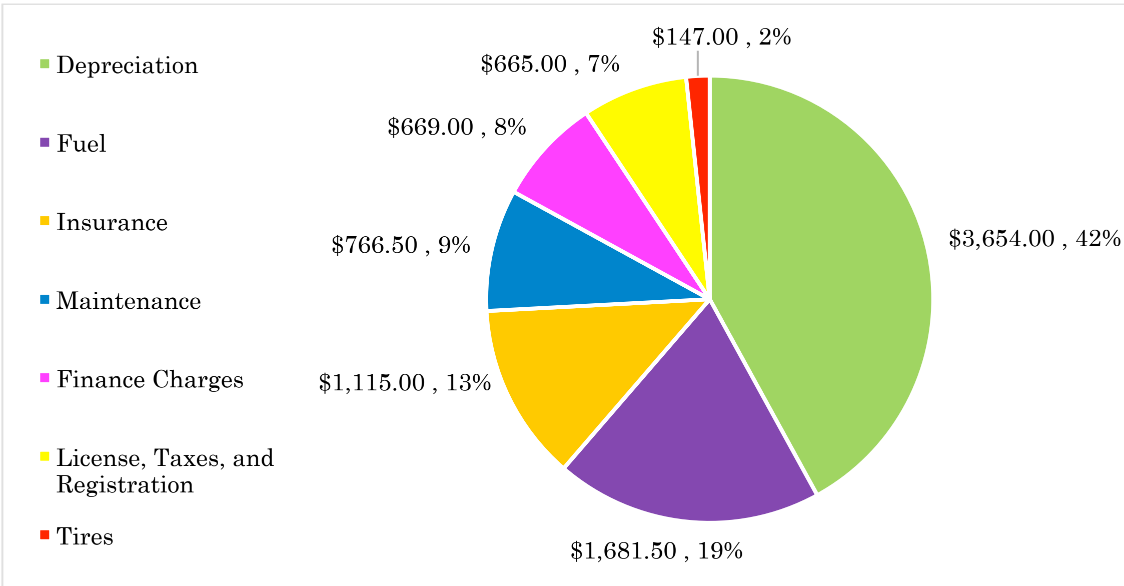
C_{AUTO} = the per mile cost of travel by auto (\$0.926/mile)

$C_{AUTO,INT,ACCIDENT}$ = the internal cost of accidents per mile driven (\$0.023/mile)

VOT_{IV} = the in-vehicle value of travel time (\$15.72/hour)

$V_{AUTO,O,D,TOD}$ = the driving speed corresponding to the origin O, destination D, and time of day TOD

The perceived cost of trips made by passenger vehicle typically consists of fuel cost alone. The American Automobile Association (AAA) produces an annual infographic displaying the annual costs of owning a vehicle. This can be found in the Appendix. AAA reports fuel cost as only 19.3% of total driving costs, as shown in Figure 2. The largest driving cost is depreciation, making up a total 42%. This could be where perceived and actual costs of driving differ the most. Typically drivers only consider the price of gasoline when making a trip, while depreciation is costing them about twice as much per mile.



Source: AAA 2015

Figure 2: Annual Driving Costs, 2015

AAA also reports total costs per mile by car size and annual VMT, as shown in Table 4. The general trends of this table show that larger vehicles cost more per mile, and cost per mile decreases as annual miles driven increases. Because the values range from 38 to 93.3 cents per mile, some important assumptions about Austin vehicle characteristics had to be made.

Table 4: Cost of Driving per Mile

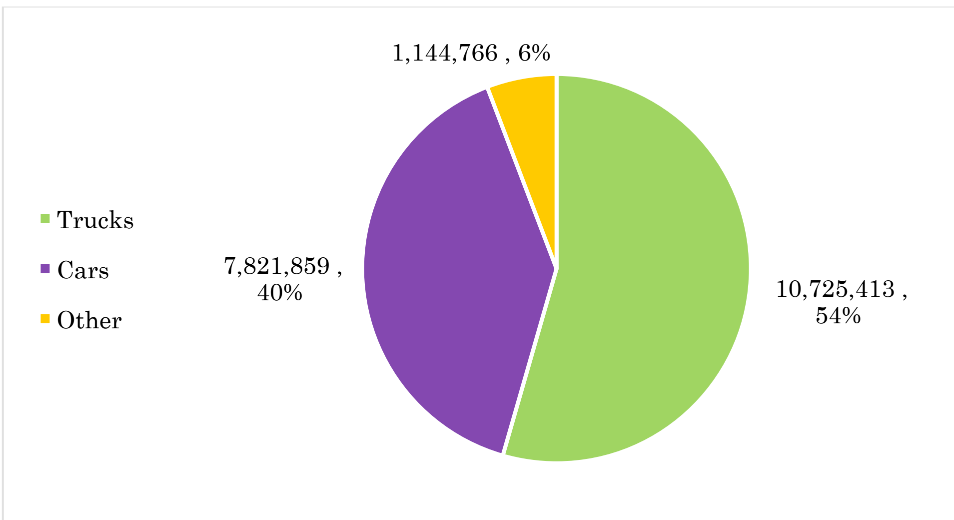
Miles per Year	10,000	15,000	20,000
small sedan	$0.582	$0.449	$0.380
medium sedan	$0.759	$0.581	$0.490
large sedan	$0.933	$0.710	$0.488
SUV	$0.926	$0.708	$0.597

minivan	\$0.812	\$0.625	\$0.529

Source: AAA 2015

To account for the varying numbers for annual per capita VMT, which are 6,439 in Travis County (TxDOT DISCOS) and 13,614 in the United States (USDOT), the value for costs per mile will assume an annual VMT of 10,000.

The Alliance of Automobile Manufacturers reports more than 50% of registered vehicles in the state of Texas as trucks (Auto Alliance). For this reason, the value for cost per mile of driving, C_{AUTO}, will assume vehicles to be SUVs (\$0.926/mile). For each cost calculation these values will be multiplied by the shortest path distance.



Source: The Alliance of Automobile Manufacturers, 2015

Figure 3: Registered Vehicles in Texas

The next factor needed to calculate the internal cost of travel by passenger vehicle is travel time. The data available from the users' inputs is the shortest path travel distance (in miles). From this we can find a travel time using an average driving speed. In order to incorporate the effects of peak hour congestion and travel direction, multiple average driving speeds had to be calculated.

First, a grid was overlaid on a map of the main transit corridors in Austin using the fishnet function in ArcMap. Because the speeds had to be calculated individually, the size of each cell in the grid was chosen to be 2.5 miles by 2.5 miles to make the process less time-consuming. A half mile buffer was applied to the transit corridors and cells that failed to intersect with it were eliminated since people in those zones would have limited access to transit. This map can be found in the Appendix (Figure 9). For future development, it is recommended to use finer detail or preferably non-square special reference, such as traffic analysis zones.

The centroids of each cell of the grid were exported and converted to latitude-longitude coordinates. Then the speeds between each centroid pair at each time of day were calculated using Google Maps. For these calculations it was assumed travel would be occurring on a future Thursday and construction interferences were neglected.

These speeds ($V_{AUTO,O,D,TOD}$) are available in a table in Tables 17-20 in the Appendix. The values on the diagonals (intra-zonal) were calculated by averaging the average of the speeds between that cell and its spatially adjacent cells. For visual reference, the green cells represent the fastest speeds and the red cells represent the slowest. The variation between the different times of day and directions validate the decision to include the level of detail rather than simply using a single average vehicle speed. For each trip the shortest path distance is divided by the speed that corresponds with the origin and destination locations and the time of day and multiplied by the value of time indicated in section 3.1.

Another component of both internal and external cost across all modes is the cost of accidents. These comprise the total costs of traffic accidents including deaths, injuries, pain, disabilities, lost productivity, grief, material damage, and accident prevention.

Zegras and Litman define these costs as society's willingness to pay for a marginal reduction in the risk of accidents. It is complicated to valuate human life, however they provide the example of paying more for a car with airbags as a decision made that trades risk of injury and death against market goods. The reported values listed in Table 5 were converted from 1994 USD per kilometer to 2015 USD per mile. The internal cost of accidents per mile driven by car ($C_{AUTO,INT,ACCIDENT}$) is $0.023.

Table 5: Accident costs per passenger mile traveled, 2015 USD per mile

Mode	Private	Public	Total
Auto	$0.023	$0.023	$0.047
Bus	$0.003	$0.003	$0.005
Bicycle	$0.016	$0.021	$0.034
Pedestrian	$0.023	$0.041	$0.065

Source: Santiago Full Cost Study, 1997

3.22 EXTERNAL (SOCIETAL) COST OF TRAVEL BY PASSENGER VEHICLE

The final equation for the estimation of the external cost of travel by passenger vehicle is shown below. Again, all costs are per mile and are therefore multiplied by the shortest path distance. The components that make up societal costs for auto travel are accidents, congestion, air pollution, noise pollution, climate change, and infrastructure.

Equation 4: External Cost of Travel by Passenger Vehicle

$$U_{AUTO,EXTERNAL} = D_{O,D}(C_{AUTO,EXT,ACCIDENT} + C_{AUTO,CONGESTION} + C_{AUTO,AIR} + C_{AUTO,NOISE,TOD} + C_{AUTO,GHG} + C_{AUTO,INF})$$

Where: $U_{AUTO,EXTERNAL}$ = the external cost of travel by passenger vehicle

$D_{O,D}$ = the shortest path distance between origin O and destination D

$C_{AUTO,EXT,ACCIDENT}$ = the external cost of accidents per mile driven ($0.023/mile)

$C_{AUTO,CONGESTION,TOD}$ = the cost of congestion per mile driven at the specified time of day ($0.02/mile for off peak times and $2.67/mile for peak hours)

$C_{AUTO,AIR}$ = the cost of air pollution per mile driven ($0.008/mile)

$C_{AUTO,NOISE,TOD}$ = the cost of noise pollution per mile driven at the specified time of day ($0.017/mile for AM Peak, $0.040/mile for Midday, $0.030/mile for PM Peak, and $0.073/mile for Nighttime)

$C_{AUTO,GHG}$ = the cost of climate change per mile driven ($0.066/mile)

$C_{AUTO,INF}$ = the cost of infrastructure per mile driven ($0.009/mile)

One external cost of traveling by motorized vehicle is congestion. A road network user affects the utility of all other users who want to use the network. Ricardo-AEA quantified these costs based on the aggregated approach of the FORGE model used in the National Transport Model of the UK. One component of this model differentiates congestion levels into 5 “bands” ranging from a volume to capacity ratio of less than 1:4 (band 1) to a v/c ratio greater than one (band 5). Metropolitan area corresponds to cities with population above 250 thousand people; urban area includes settlements with a population of more than 10 thousand people. The population in Austin is well about 250 thousand, so the Metropolitan category will be used. Because most roads in Austin are near capacity during peak hours, the “near capacity” category will be used for AM Peak and PM Peak travel times. For Midday and Nighttime travel times, the values in the “free flow” category will be used. In order to include all types of roads, the “main roads” category will be used. The tables from the Ricardo-AEA report were converted from 2010 pence per km to 2015 USD per mile and are shown in

Table **6**. The congestion cost per mile of driving a car on main roads in a metropolitan area during free flow and near capacity conditions ($C_{AUTO,CONGESTION}$), are \$0.02 and \$2.67, respectively.

Table 6: Efficient marginal congestion costs for passenger cars, 2015 USD per mile

Vehicle	Region	Road Type	Free flow	Near capacity	Over capacity
Car	Metropolitan	Motorway	$ -	$ 0.51	$ 1.16
		Main roads	$ 0.02	$ 2.67	$ 3.42
		Other Roads	$ 0.05	$ 3.01	$ 4.58
	Urban	Main roads	$ 0.01	$ 0.92	$ 1.43
		Other Roads	$ 0.05	$ 2.63	$ 4.35
	Rural	Motorway	$ -	$ 0.25	$ 0.58
		Main roads	$ 0.01	$ 0.35	$ 1.14
		Other Roads	$ 0.00	$ 0.79	$ 2.63

Source: Ricardo-AEA 2014

Another important external cost of motorized transport considered by Ricardo-AEA was the costs of air pollution. These findings can be found in Table 7. The state-of-the-art approach for evaluating air pollution effects is the damage cost approach. This method focuses on quantification of the explicit impact that the emissions have on human health, environment, economic activity, etc. A complete table of the air pollutant studies and their effects on human health can be found in the appendix (Table 23).

The air pollution costs are differentiated by vehicle, engine, EURO-class, and area type. The costs for cars are separated between diesel and petrol cars. Since most personal vehicles in Austin use gasoline, the numbers used for air pollution costs are under petrol cars. The engine types are divided into three categories by size: less than 1.4 L, between 1.4 and 2.0 L, and greater than 2.0 L. The average size of car engines in Europe is much smaller than that of cars in Austin. Since most cars being driven in Austin have engines larger than 2 L, the largest engine category will be used. The car types are further divided by EURO-class from Euro 0 to Euro 6. These classifications standardize the level of toxic emission of a vehicle. The first standards classification, Euro 1, was passed in 1992 while the most recent, Euro 6, was passed in 2014. The allowable levels of toxic emissions decrease with each new classification. Because EPA standards tend to be a bit tighter than those in Europe, the average of the air pollutions across classifications since 2005 will be used (EURO 4 – EURO 6). The costs are further differentiated by area into three categories by their population densities: urban (1,500 inhabitants/km^2), suburban (300 inhabitants/km^2), and rural (below 150 inhabitants/km^2). The population density of the city of Austin is 3,064 people per square mile (2014 Census), or 1,183 people per square kilometer. Because this is closest to the urban specification, those values will be used for estimation. The cost of air pollution effects per mile driven by passenger car ($C_{AUTO,AIR}$) is $0.008.

Table 7: Air pollution costs in 2015 USD per mile for passenger cars

Vehicle	Engine	EURO-Class	Urban	Suburban	Rural	Motorway
Car petrol	>2.0L	Euro 0	$0.072	$0.066	$0.053	$0.066
		Euro 1	$0.019	$0.013	$0.006	$0.008
		Euro 2	$0.011	$0.008	$0.004	$0.004
		Euro 3	$0.008	$0.004	$0.002	$0.002
		Euro 4	$0.008	$0.004	$0.002	$0.002
		Euro 5	$0.008	$0.002	$0.002	$0.002
		Euro 6	$0.008	$0.002	$0.002	$0.002
		AVERAGE (4-6)	$0.008	$0.003	$0.002	$0.002

Source: Ricardo-AEA, 2014

The Updated Handbook also included illustrative marginal noise costs for cars and buses (Table 8). Noise exposure not only disturbs people, but it can also result in health impairments and lost productivity and leisure. The two major impacts considered when assessing noise impacts are annoyance and health impacts. Since there was no source found of a preferred method, the 2008 Handbook values were only updated to represent 2010 Euros. That version based its recommendation for road transport on the marginal cost estimates by INFRAS/IWW (2004). The values for noise costs are differentiated based on time of day, traffic type, and area. To maintain consistency, the values for urban areas will be used in the equations for the application. Since the values are differentiated by dense and thin traffic within day and night times of day, it provides the opportunity to include this level of detail within the model. For the equations, the noise costs per mile driven by passenger vehicle ($C_{AUTO,NOISE,TOD}$) will be \$0.017 for AM Peak (dense day), \$0.040 for Midday (thin day), \$0.030 for PM Peak (dense night), and \$0.073 for Nighttime (thin night).

Table 8: Illustrative marginal noise costs, 2015 USD per mile

Mode	Time of Day	Traffic Type	Urban	Suburban	Rural
Car	Day	Dense	$0.017	$0.001	$0.000
		Thin	$0.040	$0.003	$0.000
	Night	Dense	$0.030	$0.002	$0.000
		Thin	$0.073	$0.005	$0.001

Source: Ricardo-AEA, 2014

Another externality of travel by motorized vehicle is climate change by worldwide greenhouse gas (GHG) emissions. The unit cost estimation performed by Ricardo-AEA is the Impact Pathway Approach, in which the GHG emission factors for different vehicles are quantified in tons of CO_2 equivalent per vehicle kilometer, climate change costs per ton of CO_2 are assessed, and the marginal climate change costs are calculated and shown in Table 9. As with the other values of external costs, the largest engine for passenger cars averaged across EURO-classes since 2005 in urban areas is used for the application. The estimated cost of climate change per mile driven by passenger car ($C_{AUTO,GHG}$) is \$0.066.

Table 9: Marginal climate change costs for road transport, 2015 USD per mile

Vehicle	Size	EURO-class	Urban	Rural	Motorways	Average
Passenger car - petrol	>2L	EURO-1	$0.074	$0.043	$0.043	$0.053
		EURO-2	$0.074	$0.043	$0.043	$0.051
		EURO-3	$0.066	$0.036	$0.034	$0.045
		EURO-4	$0.066	$0.036	$0.034	$0.045
		EURO-5	$0.066	$0.036	$0.034	$0.045
		AVERAGE (4-5)	$0.066	$0.036	$0.034	$0.045

Source: Ricardo-AEA, 2014

Another external cost of motorized transport is marginal infrastructure costs. These values are displayed in Table 10. Marginal road infrastructure costs correspond to the increase in road maintenance and repair expenditures that are induced by higher traffic levels. The approach used by Ricardo-AEA is similar to the approach in IMPACT D2, where the estimates are based on the available detailed road accounts. These values are differentiated by road type. For our calculations the value for all roads will be used. The per mile cost of infrastructure for cars ($C_{AUTO,INF}$) is $0.009.

Table 10: Illustrative marginal infrastructure costs for cars, 2015 USD per mile

Vehicle	All roads	Motorways	Other trunk roads	Other roads
Cars	$0.009	$0.004	$0.006	$0.015

Source: Ricardo-AEA, 2014

There is also a societal component that accounts for accidents, as shown in Table 5. The external cost of accidents per mile driven by car ($C_{AUTO,EXT,ACCIDENT}$) is $0.023.

3.3 TRANSIT BUS

Austin's regional public transportation provider is Capital Metro. Their network includes fifty Metro routes, two MetroRapid routes, eight Express routes, and nineteen UT shuttle routes, creating a total of about 3,000 bus stops throughout Central Texas. Recently, the first MetroRail passenger rail service began between the City of Leander and downtown

Austin. Capital Metro serves an area of 535 square miles and a population of 1,079,995, with 103,000 weekday boardings and 31.5 million boardings per year.

Population in Austin is increasing at a very large rate. The percent change between April 1, 2010 and July 1, 2014 was 12.5%, compared to 7.2% in all of Texas and 3.3% in the United States (US Census, 2014). With this increase comes an increased number of drivers. Since many of the roads in Austin already operate at or above capacity, it is imperative that drivers capable of traveling by another mode do so. Capital Metro is making strides in order to increase ridership, but increasing knowledge of cost might further enforce drivers to shift their mode choice.

3.31 INTERNAL (PERSONAL) COST OF TRAVEL BY TRANSIT BUS

The final equation for estimating the total internal cost of travel by bus is shown below. The first cost is the fare for the chosen bus route. Added to this are per-mile costs (internal accident cost and value of time divided by speed of chosen route at the specified time of day), which are multiplied by the shortest path distance given by the chosen origin and destination. Finally, the average time spent waiting at the bus stop is multiplied by the value of time for waiting and added for the total cost to the commuter.

Equation 5: Internal Cost of Travel by Transit Bus

$$U_{BUS,INTERNAL} = C_{BUS,RT} + D_{O,D}\left(C_{BUS,INT,ACCIDENT} + \frac{VOT_{IV}}{V_{BUS,RT,DIR,TOD}}\right) + VOT_{OV}T_{WAIT}$$

Where: $U_{BUS,INTERNAL}$ = the internal cost of travel by transit bus

$C_{BUS,RT}$ = the fare for the chosen bus route number

$D_{O,D}$ = the shortest path distance between origin O and destination D

$C_{BUS,INT,ACCIDENT}$ = the internal cost of accidents per mile of bus operation ($0.003/mile)

VOT_{IV} = the in-vehicle value of travel time ($15.72/hour)

$V_{BUS,RT,DIR,TOD}$ = the speed of the chosen bus route and direction at the chosen time of day

VOT_{OV} = the out-of-vehicle value of travel time ($31.44/hour)

T_{WAIT} = the average time spent waiting at the bus stop (5.48 minutes)

The main factor in transit cost is time. In order to compare each route by time of day and direction, many values of speed were calculated. The process used to estimate speeds is described in the following.

Using each route's schedule from the Capital Metro website, the average speed during each time of day window was calculated for each route (in each direction when applicable). These speeds, $V_{BUS,RT,DIR,TOD}$, can be found in Table 21 of the Appendix. The speeds range from 7.13 to 41.29 mph. The fastest speeds were typically found during the nighttime hours, while the slowest speeds were observed during the evening peak. The shortest path distance is multiplied by the in-vehicle value of time divided by the speed to find the cost of time spent on the bus for each user.

When calculating the time spent waiting at the bus stop, typically the square root of the headway is used. Using an assumed headway of 30 minutes, that makes the headway 5.48 minutes, or 0.0913 hours. This values seems reasonable given most commuters using public transit will have adequate knowledge of the route schedule. The out-of-vehicle value of time is multiplied by the wait time (T_{WAIT}) to determine the dollar value of waiting for the bus to be added to the total cost.

Capital Metro fares vary based on the type of transit (Table 11). For the total cost calculations, it is assumed that the rider would be paying for a non-reduced Single Ride pass. The fare for the user's chosen bus route, $C_{BUS,RT}$, is added to the total internal bus cost. The values for each specific route can be found in Table 22 in the Appendix. In further development of the equations, the user might input the type of pass they possess to more accurately calculate their internal cost of riding the bus.

Table 11: Capital Metro Pass Options and Fares

Pass Option	Local	Premium	Commuter
Single Ride	$1.25	$1.75	$3.50
Single Ride, Reduced	$0.60	$0.85	$1.75
Day Pass	$2.50	$3.50	$7.00
Day Pass, Reduced	$1.25	$1.75	$3.50
7-Day Pass	$11.25	$16.75	$27.50
31-Day Pass	$41.25	$62.00	$96.25
31-Day Pass, Reduced	$20.60	$31.00	$48.10

Source: Capital Metro, 2015

There is also an internal cost component for accident risk, as shown in Table 5. The internal cost of accidents per mile of bus operation ($C_{BUS,INT,ACCIDENT}$) is $0.003. This is the smallest value of all modes. There is a lower risk of accident cost when traveling by public transit because they travel at lower speeds than cars and provide a "protective shell" around the passengers.

3.32 EXTERNAL (SOCIETAL) COST OF TRAVEL BY TRANSIT BUS

The final equation for determining the external cost of travel by transit bus is shown below. All cost values except for taxes are per mile per bus, so they are multiplied by the shortest path distance and divided by the average vehicle occupancy. The components of external cost of travel by transit bus include accidents, congestion, air pollution, noise pollution, climate change, and infrastructure. The external cost of taxes is per passenger mile traveled by bus, so it is only multiplied by the distance.

Equation 6: The External Cost of Travel by Transit Bus

$$U_{BUS,EXTERNAL} = D_{O,D}(C_{BUS,TAXES} + \frac{C_{BUS,EXT,ACCIDENT} + C_{BUS,CONGESTION} + C_{BUS,AIR} + C_{BUS,NOISE,TOD} + C_{BUS,GHG} + C_{BUS,INF}}{VO_{BUS}})$$

Where: $U_{BUS,EXTERNAL}$ = the external cost of travel by transit bus

$D_{O,D}$ = the shortest path distance between origin O and destination D

$C_{BUS,TAXES}$ = the cost of taxes per passenger mile ($1.61)

VO_{BUS} = the average vehicle occupancy (7.91 passengers)

$C_{BUS,EXT,ACCIDENT}$ = the external cost of accidents per mile of bus operation ($0.003/mile)

$C_{BUS,CONGESTION}$ = the cost of congestion per mile of bus operation at the specified time of day ($0.02/mile for off-peak and $2.67/mile for peak hours)

$C_{BUS,AIR}$ = the cost of air pollution per mile of bus operation ($0.109/mile)

$C_{BUS,NOISE,TOD}$ = the cost noise pollution per mile of bus operation at the specified time of day ($0.083/mile for AM Peak, $0.202/mile for Midday, $0.151/mile for PM Peak, and $0.367/mile for Nighttime)

$C_{BUS,GHG}$ = the cost of climate change per mile of bus operation ($0.140/mile)

$C_{BUS,INF}$ = the cost of infrastructure per mile of bus operation ($0.038/mile)

One component considered for external costs of travel by transit bus is congestion. The values calculated by Ricardo-AEA also included those for buses (Table 12). Their congestion cost per mile of operating a bus on main roads near capacity in a metropolitan area is \$6.66. This number is much larger than expected, and significantly larger than the congestion cost values for cars in near capacity conditions. This can be explained by the methodology used by Ricardo-AEA where vehicle types were given corresponding passenger car unit values (2.5 for bus). It seems as though cost values for bus are simply 2.5 times those for passenger cars. During near capacity conditions, this is most likely not the case, because the difference in lost time caused by cars and buses would be much smaller during peak hours. To correct for this, the congestion cost value calculated for passenger vehicles during near capacity conditions will also be used for buses during peak hours (\$2.67). The calculated bus value for free flow conditions (\$0.04) will be used for off-peak times ($C_{BUS,CONGESTION}$).

Table 12: Efficient marginal congestion costs for buses, 2015 USD per mile

Vehicle	Region	Road Type	Free flow	Near capacity	Over capacity
Bus	Metropolitan	Motorway	\$0.00	\$1.26	\$2.90
		Main roads	\$0.04	\$6.66	\$8.55
		Other Roads	\$0.12	\$7.52	\$11.44
	Urban	Main roads	\$0.03	\$2.30	\$3.58
		Other Roads	\$0.12	\$6.57	\$10.87
	Rural	Motorway	\$0.00	\$0.63	\$1.45
		Main roads	\$0.02	\$0.86	\$2.86
		Other Roads	\$0.01	\$1.98	\$6.57

Source: Ricardo-AEA, 2014

In order to accurately include this for a single transit rider's external costs, the total cost per mile of bus operation is divided by the average number of bus riders. Capital Metro's 2012 Quadrennial Performance Review includes information about average vehicle occupancy. This is computed by dividing the annual passenger miles by the miles traveled by authority revenue vehicles in revenue service for the same time period. In 2011, the average vehicle occupancy by all modes except vanpool (motor bus, demand response (DR), directly operated motor bus and DR, and rail), VO_{BUS}, was 7.91 passengers.

The external costs of air pollution were calculated by Ricardo-AEA for transit buses as well and can be found in

Table 13. Like passenger vehicles, they were differentiated by vehicle category, EURO-class, and area. The vehicle categories given for urban buses were midi, standard, and articulated. The values for standard-sized buses will be used in the equations for the applications. As done for the passenger vehicle air pollution costs, the average across EURO-classes since 2005 is taken, and the values for urban areas are used. The cost of air pollution per mile of bus operation ($C_{BUS,AIR}$) is \$0.109. This number will also be divided by the vehicle occupancy.

Table 13: Air pollution costs in 2015 USD per mile for urban buses

Vehicle	Engine	EURO-Class	Urban	Suburban	Rural	Motorway
Urban Buses	Standard 15 - 18 t	Euro 0	\$0.671	\$0.409	\$0.289	\$0.243
		Euro 1	\$0.398	\$0.247	\$0.174	\$0.147
		Euro 2	\$0.328	\$0.236	\$0.175	\$0.149
		Euro 3	\$0.277	\$0.196	\$0.136	\$0.109
		Euro 4	\$0.162	\$0.126	\$0.092	\$0.074
		Euro 5	\$0.130	\$0.094	\$0.053	\$0.041
		Euro 6	\$0.036	\$0.015	\$0.008	\$0.006
		AVERAGE (4-6)	\$0.109	\$0.079	\$0.051	\$0.040

Source: Ricardo-AEA, 2014

The noise pollution costs are listed in Table 14. For the equations, the noise costs per mile of bus operation in an urban area ($C_{BUS,NOISE,TOD}$) will be \$0.083 for AM Peak (dense day), \$0.202 for Midday (thin day), \$0.151 for PM Peak (dense night), and \$0.367 for Nighttime (thin night). These values will also be divided by the vehicle occupancy.

Table 14: Illustrative marginal noise costs for buses, 2015 USD per mile

Mode	Time of Day	Traffic Type	Urban	Suburban	Rural
Bus	Day	Dense	$0.083	$0.005	$0.001
		Thin	$0.202	$0.013	$0.002
	Night	Dense	$0.151	$0.008	$0.001
		Thin	$0.367	$0.024	$0.003

Source: Ricardo-AEA, 2014

The climate change costs calculated by Ricardo-AEA are listed in Table 15. The cost of climate change per mile of bus operation in an urban area ($C_{BUS,GHG}$) is $0.140.

Table 15: Marginal climate change costs for buses, 2015 USD per mile

Vehicle	EURO-class	Urban	Rural	Motorways	Average
Buses	EURO-1	$0.145	$0.109	$0.100	$0.119
	EURO-2	$0.143	$0.106	$0.096	$0.115
	EURO-3	$0.143	$0.106	$0.096	$0.115
	EURO-4	$0.140	$0.096	$0.087	$0.109
	EURO-5	$0.140	$0.096	$0.087	$0.109
	AVERAGE (4-5)	$0.140	$0.096	$0.087	$0.109

Source: Ricardo-AEA, 2014

The marginal infrastructure costs for buses calculated by Ricardo-AEA are listed in Table 16. The cost of infrastructure per mile of bus operation ($C_{BUS,INF}$) is $0.038.

Table 16: Illustrative marginal infrastructure costs for buses, 2015 USD per mile

Vehicle	All roads	Motorways	Other trunk roads	Other roads
Buses	$0.038	$0.015	$0.026	$0.051

Source: Ricardo-AEA, 2014

Another external cost of commuting by bus is the use of tax dollars. Within its service area, Capital Metro receives 1% of sales tax for funding. The 2016 Fiscal Year Budget Summary estimates this as $217 million. Divided by 134.6 million annual passenger miles, that makes the tax cost per bus per mile ($C_{BUS,TAX}$) $1.61.

The cost of accident risk is also borne externally for buses, as shown in Table 5. The external cost of accidents per mile of bus operation ($C_{BUS,EXT,ACCIDENT}$) is \$0.003.

3.4 CYCLING

The Alliance for Biking and Walking reports that 1.3% of commuters in Austin commute by bicycle, the 15th largest share among cities in the United States. Among those commuting by bike, only 25% are female. This may be due to the clothing women wear to work and the clothing worn to ride a bike or something else about biking and work appearance differences. Austin had the most miles of signed bicycle routes (983 miles). The share of commuters biking to work might be larger if there were more biking facilities available.

3.41 INTERNAL (PERSONAL) COST OF TRAVEL BY CYCLING

The final equation for determining the internal cost of travel by cycling is shown below. All cost values are in dollars per mile and are multiplied by the shortest path distance between the given origin and destination. The components included in this calculation are the cost given by bike ownership, accidents, and value of time divided by the average cycling speed.

Equation 7: Internal Cost of Travel by Cycling

$$U_{BIKE,INTERNAL} = D_{O,D}\left(C_{BIKE} + C_{BIKE,INT,ACCIDENT} + \frac{VOT_{IV}}{V_{BIKE}}\right)$$

Where: $U_{BIKE,INTERNAL}$ = the internal cost of travel by cycling

$D_{O,D}$ = the shortest path distance between origin O and destination D

C_{BIKE} = the per mile cost of travel by bike (\$0.10/mile)

$C_{BIKE,INT,ACCIDENT}$ = the cost of accidents per mile traveled by bike (\$0.016/mile)

VOT_{IV} = the in-vehicle value of travel time ($15.72/hour)

V_{BIKE} = the average cycling speed (12mph)

The biggest component in the cost of a bicycle trip is the trip time. The Oregon Transportation Research and Education Consortium (OTREC) estimates the average bicycle speed for work, work-related, and school trips to be 12.0 mph (OTREC, 2008). This is the number that will be used for the biking speed for all times of day (V_{BIKE}), since peak hour has little to no impact on biking speed. The distance between the chosen origin and destination will be multiplied by the in-vehicle value of time divided by the biking speed to find the travel time cost component.

The Victoria Transport Policy Institute performed a Transportation Cost and Benefit Analysis in 2007 and reported the results for vehicle ownership costs. Under the assumptions that the bike and accessories cost a total of $500-1,000, or $50-100 annually over a ten-year operating life, plus $50-200 annually for maintenance, and is ridden 2,000 miles annually, the total cost per mile of riding a bike is 5-15 cents. Using these assumptions, the cost per mile of riding a bike (C_{BIKE}) will be $0.10. This number will be multiplied by the OD distance.

Accident risk is also included in internal cost of cycling. The Alliance for Biking and Walking reports a bicyclist fatality rate in Austin of 2.4 per 10,000 biking commuters, the 11th lowest in the nation. This number represents 0.8% of all traffic fatalities. As shown in Table 5, the internal cost of accidents per mile cycled ($C_{BIKE,INT,ACCIDENT}$) is $0.016.

3.42 EXTERNAL (SOCIETAL) COST OF TRAVEL BY CYCLING

The final equation for determining the external cost of travel by cycling is shown below. The only components of societal cost of bike travel are accidents and health benefits, which are in dollars per mile and therefore multiplied by the shortest path distance between the given origin and destination.

Equation 8: External Cost of Travel by Cycling

$$U_{BIKE,EXTERNAL} = D_{O,D}(C_{BIKE,EXT,ACCIDENT} + B_{BIKE,HEALTH})$$

Where: $U_{BIKE,EXTERNAL}$ = the internal cost of travel by biking

$D_{O,D}$ = the shortest path distance between origin O and destination D

$C_{BIKE,EXT,ACCIDENT}$= the external cost of accidents per mile biked ($0.021/mile)

$B_{BIKE,HEALTH}$ = the healthcare savings per mile walked (-$0.085/mile)

The 1997 Full Cost Study values for accident cost per mile can be found in Table 5. The external cost of accidents per mile biked ($C_{BIKE,EXT,ACCIDENT}$) is $0.021.

There is also a benefit to society when people choose active modes of transportation. George Poulos suggests the healthcare savings that result from partaking in active transportation per mile of biking (B_{HEALTH}) are equal to -$0.085 (Poulos).

3.5 WALKING

The Alliance for Biking and Walking reports a 2.6% mode share for walking in Austin, the 28th highest among cities in the United States. One reason this number might not be higher is that the climate in Austin is particularly warm compared to other cities in the US and people may be discouraged from walking their commute if it is too hot. Another reason might be that Austin's central business district is smaller than other cities where a larger share of people live within walking distance of their work. Austin has 3,500 planned miles of pedestrian ways, more than any other city in the US. This action has the potential to increase the walking share of commuters significantly.

3.51 INTERNAL (PERSONAL) COST OF TRAVEL BY WALKING

The final equation for determining the internal cost of travel by walking is shown below. The internal cost components of walking are the cost of shoes, accidents, and value of time divided by average walking speed. These values are in dollars per mile and are multiplied by the shortest path distance between the origin and destination.

Equation 9: Internal Cost of Travel by Walking

$$U_{WALK,INTERNAL} = D_{O,D}(C_{WALK} + C_{WALK,INT,ACCIDENT} + \frac{VOT_{IV}}{V_{WALK}})$$

Where: $U_{WALK,INTERNAL}$ = the internal cost of travel by walking

$D_{O,D}$ = the shortest path distance between origin O and destination D

C_{WALK}= the per mile cost of travel by walking ($0.02/mile)

$C_{WALK,INT,ACCIDENT}$=the internal cost of accidents per mile walked ($0.023)

VOT_{IV} = the in-vehicle value of travel time ($15.72/hour)

V_{WALK} = the average walking speed (4 mph)

One of the main reasons the mode share for commute trips made by walking is so low is because walking is the slowest mode of transportation. Although it is also the cheapest mode when it comes to initial costs, it isn't chosen unless the distance is fairly short. According to the National Household Transit Survey, the average commute speed of trips made by walking in 2009 was 4.77 mph and the average trip length was just under a mile (Santos). This value is much larger than expected, as typical calculations involving walking speed use 3 or 3.5 mph. While it is assumed that those people commuting would be walking faster than the typical leisure walking speed, a value of 4 mph will be used in calculations to compromise.

The VTPI also noted that walking shoes typically last 500-5,000 miles walked. Assuming the average pair of sneakers costs about \$50 and lasts 2,500 miles, the total cost of walking per mile (C_{WALK}) is \$0.02.

The Alliance for Biking and Walking reports a pedestrian fatality rate in Austin of 14.0 per 10,000 walking commuters. This number represents 27.5% of all traffic fatalities. As shown in Table 5, the internal cost of accidents per mile walked ($C_{WALK,INT,ACCIDENT}$) is \$0.023.

3.52 EXTERNAL (SOCIETAL) COST OF TRAVEL BY WALKING

The final equation for determining the external cost of travel by walking is shown below. The societal cost components of walking are accidents and health benefits. These values are in dollars per mile and are multiplied by the shortest path distance between the origin and destination.

Equation 10: The External Cost of Travel by Walking

$$U_{WALK,EXTERNAL} = D_{O,D}(C_{WALK,EXT,ACCIDENT} + B_{WALK,HEALTH})$$

Where: $U_{WALK,EXTERNAL}$ = the internal cost of travel by walking

$D_{O,D}$ = the shortest path distance between origin O and destination D

$C_{WALK,EXT,ACCIDENT}$= the external cost of accidents per mile walked (\$0.041/mile)

$B_{WALK,HEALTH}$ = the healthcare savings per mile walked (-\$0.15/mile)

The 1997 Full Cost Study values for accident cost per mile can be found in Table 5. The external cost of accidents per mile walked ($C_{WALK,EXT,ACCIDENT}$) is \$0.041.

There is also a benefit to society when people choose active modes of transportation. George Poulos examined healthcare savings and his work was used by Millar who suggests the healthcare savings that result from partaking in active transportation per mile of walking ($B_{WALK,HEALTH}$) are equal to -\$0.15 (Poulos).

4 FINDINGS

An example of what the outputs might look like is shown below using the equations developed in Chapter 3. For this example, it is assumed that the User has input an origin close to the West Gate and Western Trails bus stop, a destination close to the Austin State Hospital, and knowledgeably chose the 338 North Bus Route. The time of departure chosen is 7:30 AM, within the morning peak. As shown in the zone label chart in the appendix, the origin is in zone 6 and the destination is in zone 22. From inputting the origin and destination in Google Maps, we get a shortest path distance of 7.5 miles. The results are shown below. For this trip, it would be cheapest for the user to travel by bike, followed by auto and bus. However, they would benefit society by walking or biking.

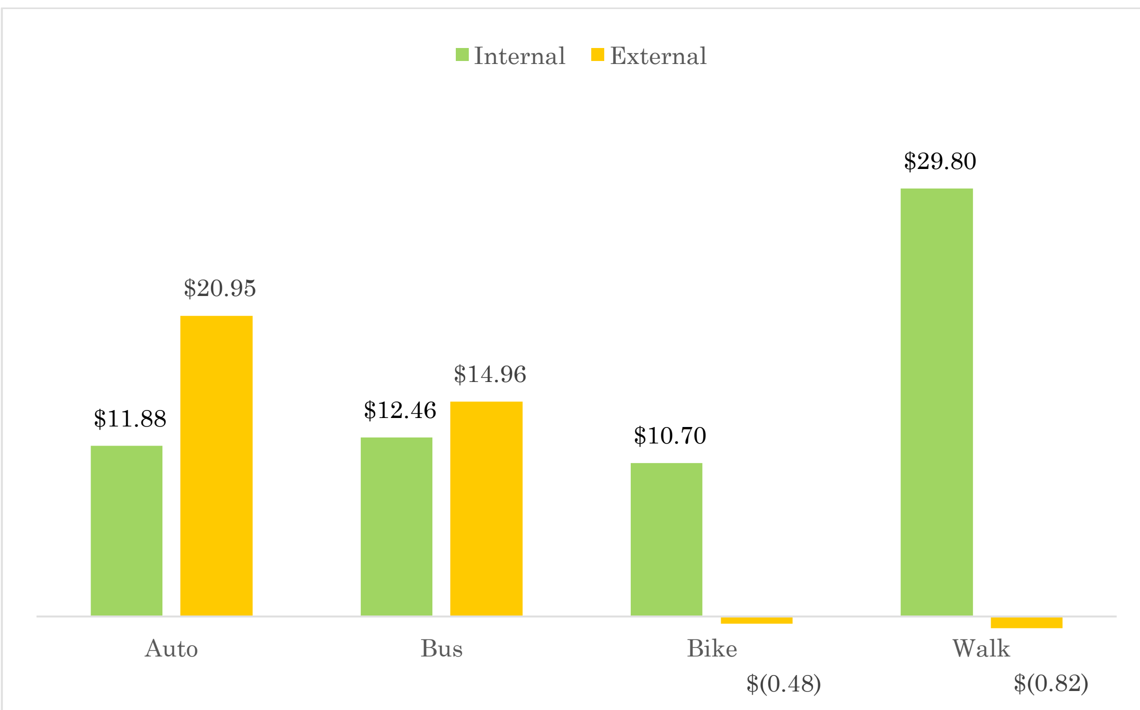


Figure 4: Internal and External Costs by Mode (example)

Next we'll compare the sensitivity of each mode cost to distance. Note that the bus and auto speeds will remain constant. You can see below that walking is the most expensive mode, especially for long trips, due to the very slow speed. As trip distance exceeds three miles, bike becomes most cost effective, followed by auto and bus. However, taking the bus becomes less expensive as the trip distance exceeds nine miles.

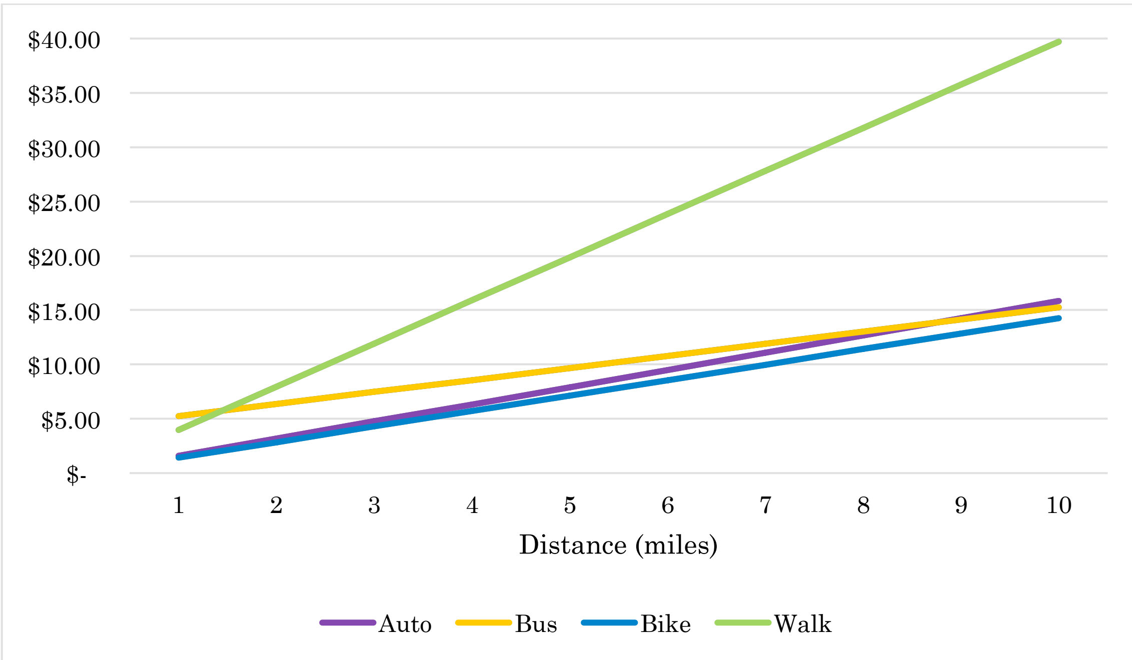


Figure 5: Internal Cost by Distance (0-10 miles)

In the next figure you can see that for trips less than 1.5 miles, transit bus is the most expensive mode choice. This makes sense because it is the only equation with a fixed cost, accounting for the bus fare and the time spent waiting at the bus stop. Auto costs are less than bus for all short trips, however this is due to the lack of a fixed cost in the equation. For short trips, the most cost-efficient mode is biking.

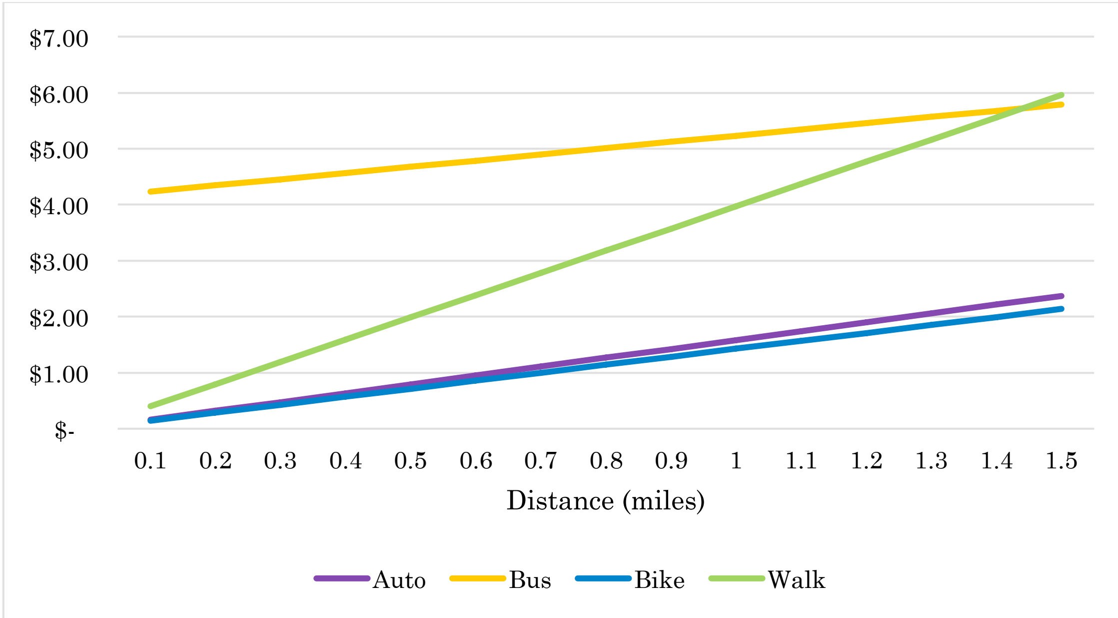


Figure 6: Internal Cost by Distance (0-1.5 miles)

This final figure below shows the external cost by distance. These results are expected, with auto having the largest costs to society, followed by bus. Being the only vehicular mode choices included, they are the only ones impacting the network and creating emissions that affect society. Bike and walking modes have increasingly negative costs (benefits) to society, because they create no emissions and have negligible effects on the network.

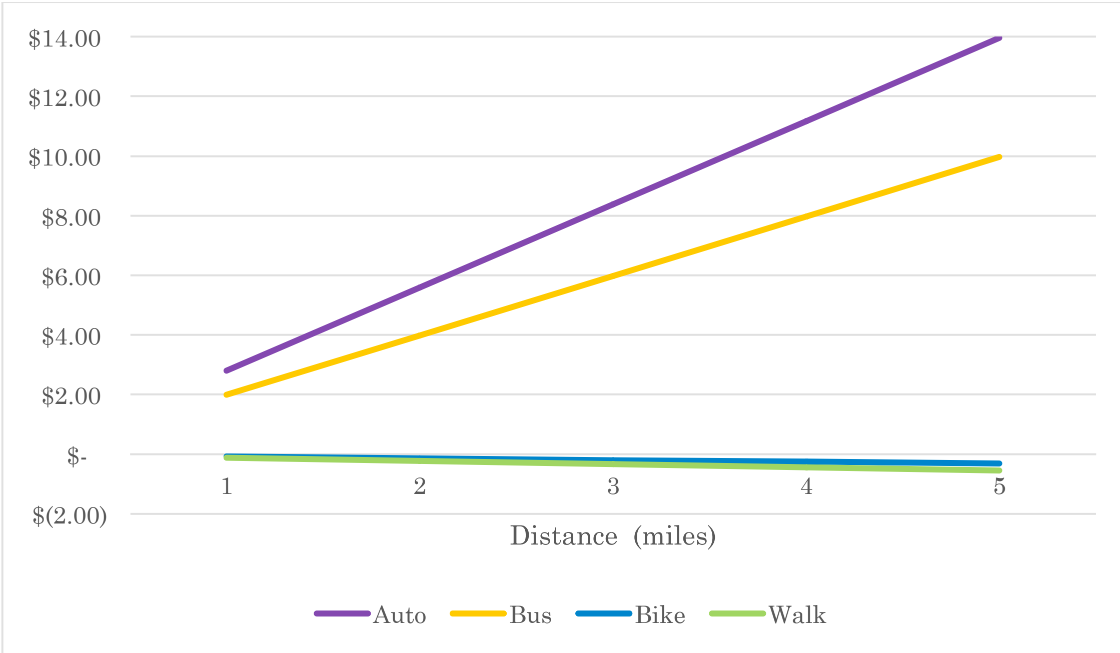


Figure 7: External Costs by Distance (0-5 miles)

5 FURTHER EXPLORATION

One major difficulty with this research was a lack of data. With more data, this application could be streamlined to be much more accurate, especially regarding the passenger vehicle speeds. The accident costs could also be calibrated if there was data on annual costs of fatal accidents by vehicle type.

The product would become exponentially more useful if it did not require the user to input their bus route. If the application could recommend a bus route based on the user's commute, it would become much more applicable and useful to residents of Austin. Having reference to Capital Metro's existing Trip Planner would also eliminate the need to constantly update the bus route speeds. This also would present the possibility of estimating speeds in real-time.

These equations could also be applied to cities similar to Austin that are looking to decrease congestion, increase public transit, or simply increase the knowledge of their commuters. Future developments might include modes for rail, motorcycle, taxi, and air as well.

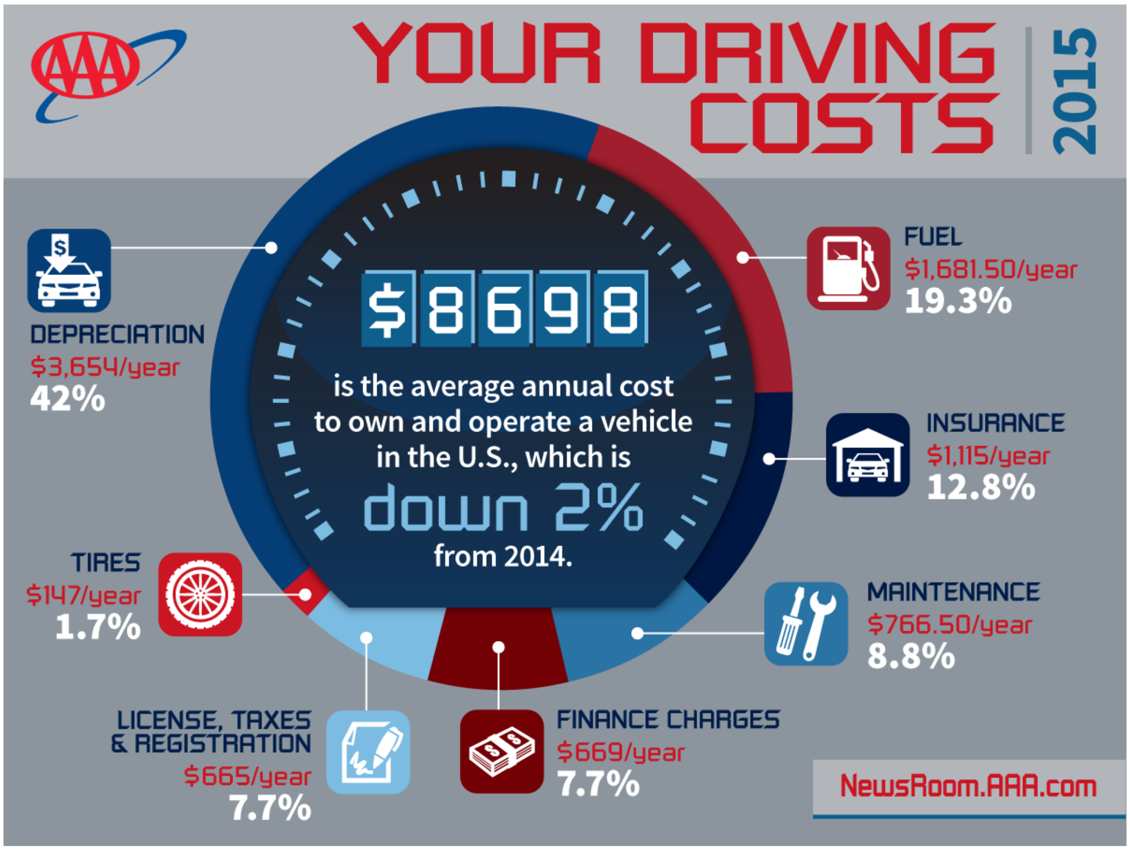
6 CONCLUSION

The equations developed in this paper are meant for use in a web application for Capital Metro. They are meant to exist as a foundation to be built upon with the availability of information. While external costs are rarely considered, new technologies have allowed us to estimate some of the societal factors that are significant yet ignored. It comes as no surprise that in most cases it is most harmful to society for commuters to travel by passenger car. However, the transit bus option could be even further improved by simply increasing ridership. Walking and biking may not seem like a possibility for most commuters, but it makes financial sense at both the individual and societal level to travel by active transport on short trips.

The main purpose of this research is to increase the knowledge of Austin commuters. With detailed information that is personalized to each user, consumers would be able to make more intelligent travel decisions. If the congestion in Austin hasn't already made commuters consider changing their mode of travel, maybe putting a dollar value on it will.

The cost items included in the equations were selected based upon what other investigators have chosen, as well as, judgment regarding what is most important for Austin travelers. Clearly additional costs could be included, however, those items selected for inclusion represent a comprehensive summary.

APPENDIX



Source: AAA 2015

Figure 8: AAA Annual Costs of Driving

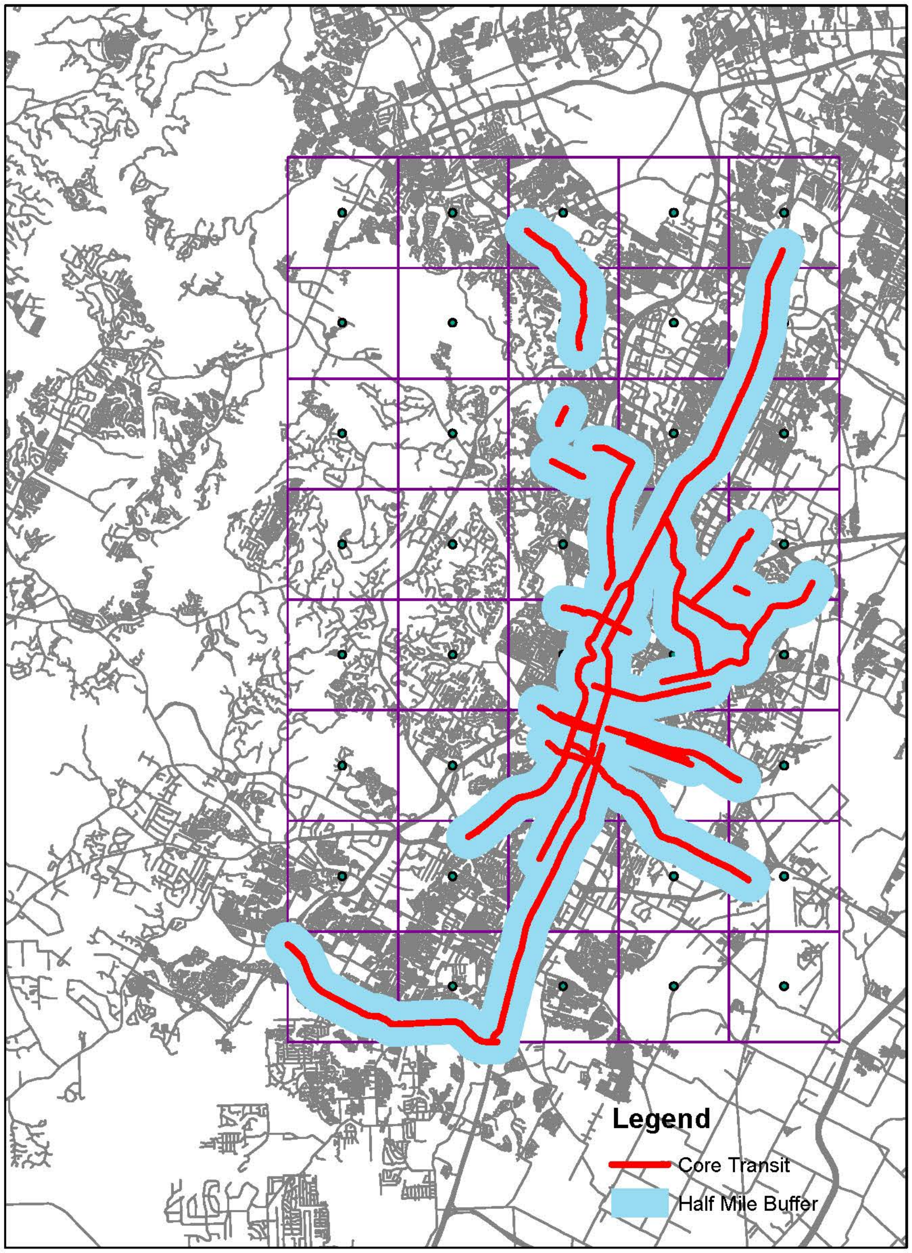


Figure 9: ArcGIS Map of Transit Corridor Zones

35	36	37	38	39
30	31	32	33	34
25	26	27	28	29
20	21	22	23	24
15	16	17	18	19
10	11	12	13	14
5	6	7	8	9
0	1	2	3	4

Figure 10: Zone Labels for Auto Speed Calculations